DEC STD 067-3 Handling of Electrostatic Sensitive Devices: Manufacturing Facilities

DOCUMENT IDENTIFIER: A-DS-EL00067-03-0000 Rev A, 18-Jun-1990

ABSTRACT: This standard provides requirements for limiting Electrostatic Discharge (ESD) for manufacturing products. It establishes a corporate wide static control program for use in the manufacture of products.

APPLICABILITY: The requirements of this document are mandatory for all facilities involved in the manufacturing, testing, repair, and refurbishing of products. This includes storage and distribution as well as other manufacturing support functions. This standard should be imposed on outside vendors that supply to Digital.

STATUS: APPROVED 18-Jun-1990; use VTX SMC for current status.

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1 INTRODUCTION

Static electricity, the transfer of electrons from one object to another, produces different levels of electrostatic discharge (ESD). Different levels of ESD may harm or destroy products. To protect products from ESD damage, a complete, corporate-wide static control program is necessary. ESD protection schemes must be employed within the areas of product design development, and the work environment.

1.1 PURPOSE

This document establishes a corporate-wide static control program for use in the manufacturing of products that limits the risk of ESD damage. It addresses protection procedures for the following.

- Handling and storage
- Training requirements for the several disciplines employed in the manufacturing operation
- Equipment needed for monitoring and operating an ESD protected area
- Specialized applications

1.2 SCOPE

This standard applies to all areas where electrostatic discharge (ESD) sensitive products are handled. This includes all manufacturing processes as well as test, rework, storage, distribution, and support operations. In addition, this standard should be imposed on outside vendors that supply to Digital.

1.3 RESPONSIBILITIES

The following manufacturing areas are responsible for the implementation of this standard.

- Manufacturing operations management is responsible for manufacturing areas and the personnel working in these areas. Refer to Section 4 of this standard for general protection procedures and Section 17 for training personnel.
- Manufacturing Engineering and Industrial Engineering shall be observant of ESD control methods and procedures when supporting manufacturing operations.
- Operational personnel shall use the protective material supplied to them. Personnel shall notify the supervisor or manager when ESD damage is suspected or control measures are suspected to be insufficient for adequate protection. Additionally, operational personnel are responsible for maintaining their ESD certification or training requirements, as available.
- Purchasing shall specify ESD protective packaging for all ESD sensitive product supplied to the manufacturing operation. They shall select ESD protective materials, control equipment, and test equipment from the recommended product lists or from the qualified products lists maintained by EOS/ESD Control Engineering.

- Incoming inspection areas shall check for ESD protective packaging materials on all incoming ESD sensitive products. These areas shall test lots of ESD protective packaging materials (to be used by manufacturing) for conformance to the purchasing specification as defined in *DEC STD 067-2 Electrostatic Discharge-Sensitive Devices: Procedures and Protective Packaging Materials* and to *EL-MF067-00-A, Incoming Inspection of Packaging Material.*
- EOS/ESD Control Engineering shall maintain this document and aid in the implementation of its procedures.

2 STATIC ELECTRICITY

Static electricity is an electrical charge at rest on the surface of an object. An electrostatic discharge (ESD) occurs when that charge transfers to another object and energy is exchanged. The energy levels are governed by the following relationship.

$$W = \frac{CV^2}{2}$$

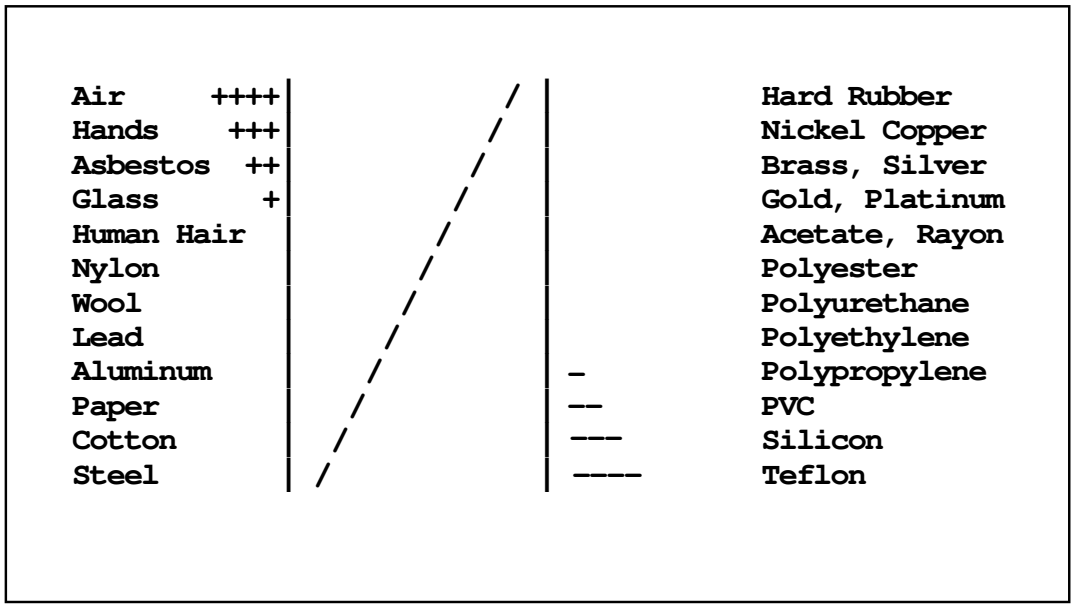
Where: W = Energy Stored on a body in Joules (watt-seconds)
C = Capacitance of a body in Farads
V = Potential on a body in volts

2.1 TRIBOELECTRIC GENERATION

Static electricity is caused by triboelectric generation, the rubbing or bringing in to contact and separation of two materials. Triboelectric generation is frequently described with a triboelectric series. Refer to Figure 1.

Static charge can be developed through triboelectric generation on both conductors and insulators. Conductors can discharge at high currents by contacting another conductor. Insulators must be exposed to free ions to discharge. Charged insulators are capable of inducing a field onto a conductor. It is for this reason that insulators in the work area are so dangerous. For example, a vinyl note book can be charged to thousands of volts and repeatedly induce a static field onto a conductor and cause an ESD.

Figure 1: Triboelectric Series



This series lists materials in order of their relative probability to take on positive or negative charge through friction.

NOTE

Triboelectric generation is governed by a variety of factors, and under different conditions, materials may not act in accordance with the triboelectric series. Therefore, the series should be used only as an informational guide and not as a scientific tool.

2.2 GENERAL ESD PROTECTION PRACTICES

Products are protected by implementing these three protection principles.

1. Surround products with ESD protective material.
2. Remove all sources of charge.
3. Maintain all personnel, surfaces, and equipment at ground potential.

By instituting these protection practices, the cost of ESD related damage can be minimized. These practices increase the long term reliability of products by reducing the occurrence of latent failures. This lowers costs in terms of warranty service requests, and increases customer satisfaction. Experience indicates that an average of nine latent failures leave the factory for every total failure discovered and repaired.

3 REQUIREMENTS FOR A STATIC CONTROL PROGRAM

The requirements for an efficient static control program are:

1. Training and certification of personnel. Refer to Section 17 for training information.
2. Setting up an ESD controlled area. Refer to Section 4 for equipment setup and operational procedures.
3. Appointing an ESD Control Program Leader responsible for organizing static control efforts. Refer to Section 3.1 for more information.

3.1 SAMPLE JOB DESCRIPTION: ESD CONTROL PROGRAM LEADER

A program leader requires full management support and the authority to require training and site preparation measures. For a program to function efficiently, it is imperative that the personnel involved be informed of static control methods, operational procedures, and correct equipment. Compliance to ESD control procedures should be included in the review of personnel working with ESD sensitive components.

The primary responsibilities of an ESD Control Program Leader are to:

- Provide a contact point for collecting and distributing information on ESD.
- Interface with area personnel from operations to managerial staff, and implement training for full static electricity control.
- Provide a single informational exchange with external groups. This person is not required to know everything about ESD, but is required to set up a network to find the required ESD control information.
- Use this standard to delineate an area-specific ESD protection program.
- Coordinate or perform audits for compliance to the requirements of this standard, and implement remedial action for noncompliant situations.
- Contribute to or chair the "Business Operations Committee". Assist in documenting procedures and specifications used in manufacturing.
- Maintain contact with corporate and industry groups active in ESD control, stay abreast of technology advances, and implement these advances as applicable.
- Interface with inside and outside vendors to explain ESD control requirements as they apply to operational needs.
- Assist in the evaluation of vendor conformance to ESD specifications.

3.1.1 Experience Required

The ESD Control Program Leader shall provide solutions to a wide range of ESD control problems, using adaptability and imagination to come up with the best solutions. This requires a wide application of ESD principles, theories, and concepts as well as good networking capabilities to locate available answers.

Education shall be a BS in Engineering, or equivalent experience in Manufacturing and/or Quality Control Engineering that includes knowledge in some of the following areas.

- Electrostatic Physics
- ESD Control Methods
- ESD Protective Material Evaluation
- Training and Presentation Methods
- Audit Methods

3.1.2 Impact of ESD Control Program Leader

The impact of this position shall result in:

- Decreased ESD-induced faults
- Improved productivity and reliability
- Increased mean-time-between-failures
- Improved customer satisfaction and lowered product cost

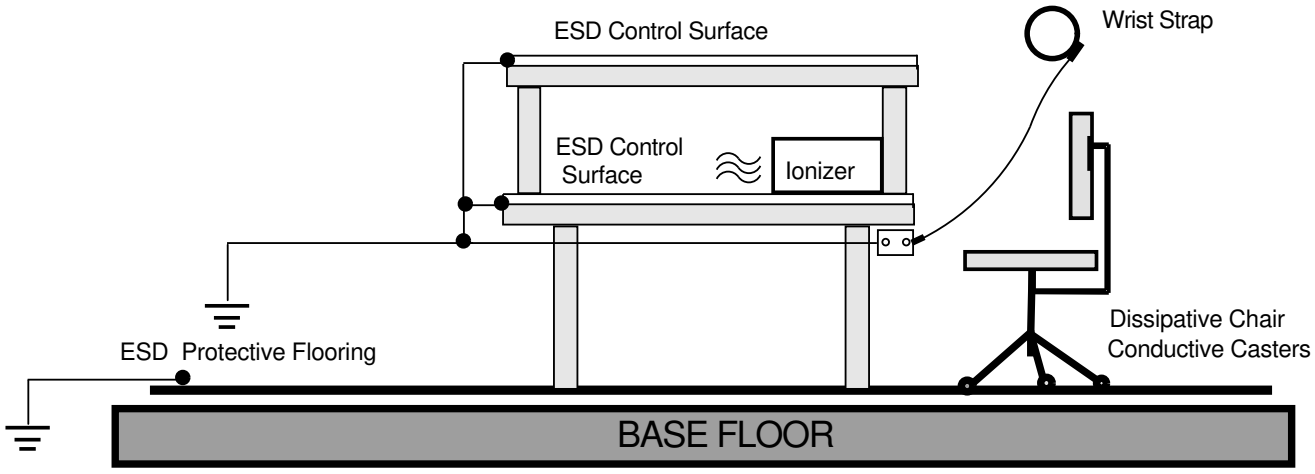
4 ESD PROTECTIVE WORKSTATION REQUIREMENTS

An ESD Protective Workstation provides the necessary controls for the safe handling of ESD susceptible components, assemblies, and product. The size and shape of the workstation depends on the nature of the work performed. Refer to Section 5 for ESD Protective Area Requirements.

4.1 TYPICAL WORKSTATION SETUPS

A workstation can be as comprehensive as a workbench with built-in control surfaces, a monitor, ground connections, floor mats, signs, tools, and more, or it may be as simple as a clear area and a portable mat and grounding kit. Refer to Figure 2 through Figure 7 for examples of typical workstation setups.

Figure 2: Typical ESD Protective Workstation



Rules:

1. ESD–protective footwear is required.

2. Wrist Strap must be worn when seated.

3. Remove all nonessential material.

4. Run ionizer during charge generating operations and to remove charge from insulators near ESD sensitive material.

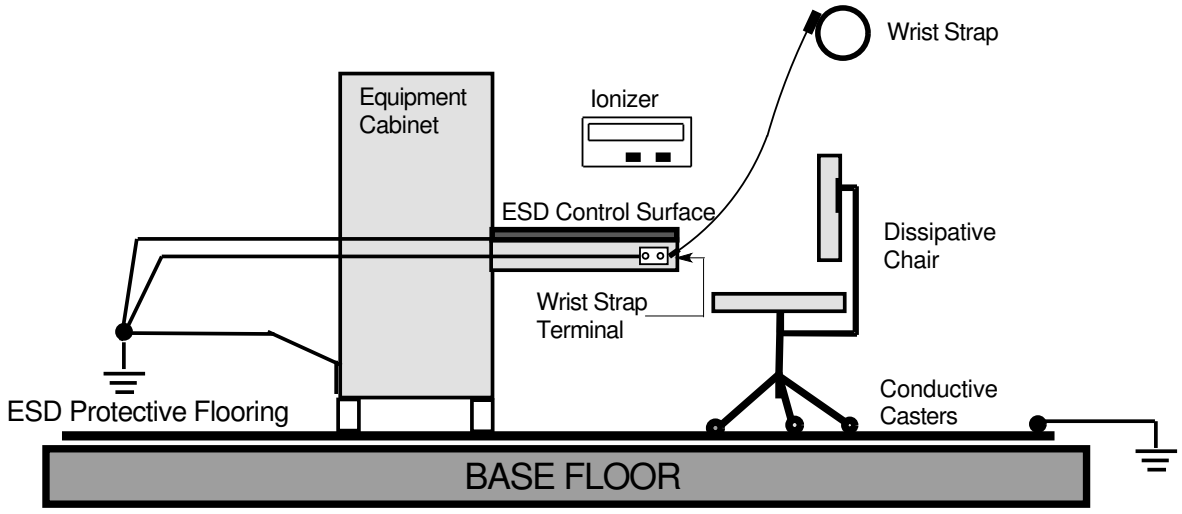
5. Keep all ESD–sensitive material ESD–protected when not being worked on.

6. Treat plastic surfaces to prevent charge generation and monitor periodically.

7. Ground all containers while transferring ESD sensitive contents.

8. ESD protective garments are required in all areas where ESD sensitive material is handled.

Figure 3: Typical ESD Protective Test Equipment Workstation

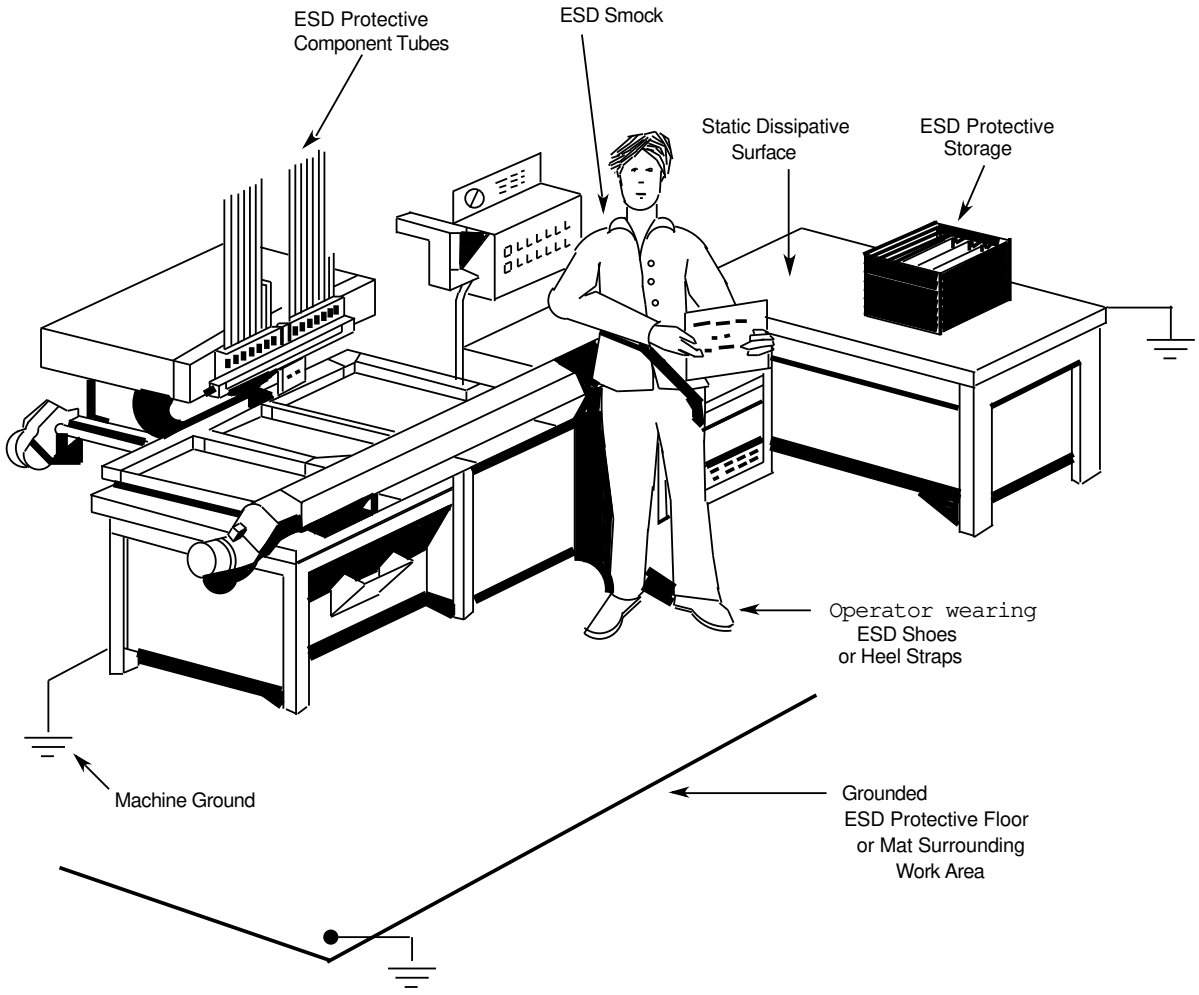


The following rules shall be followed when working at a test equipment workstation.

Rules:

1. ESD protective footware shall be worn.
2. Wrist straps shall be worn when seated.
3. ESD smocks shall be worn.
4. Nonessential material shall be removed.
5. ESD sensitive material shall be kept in a protected package or container unless being worked on.
6. Plastic surfaces shall be treated and monitored to prevent charge generation.
7. Containers shall be grounded when transferring ESD sensitive contents.
8. Test heads shall be monitored for static charges and maintained in a neutral state with ionizers.

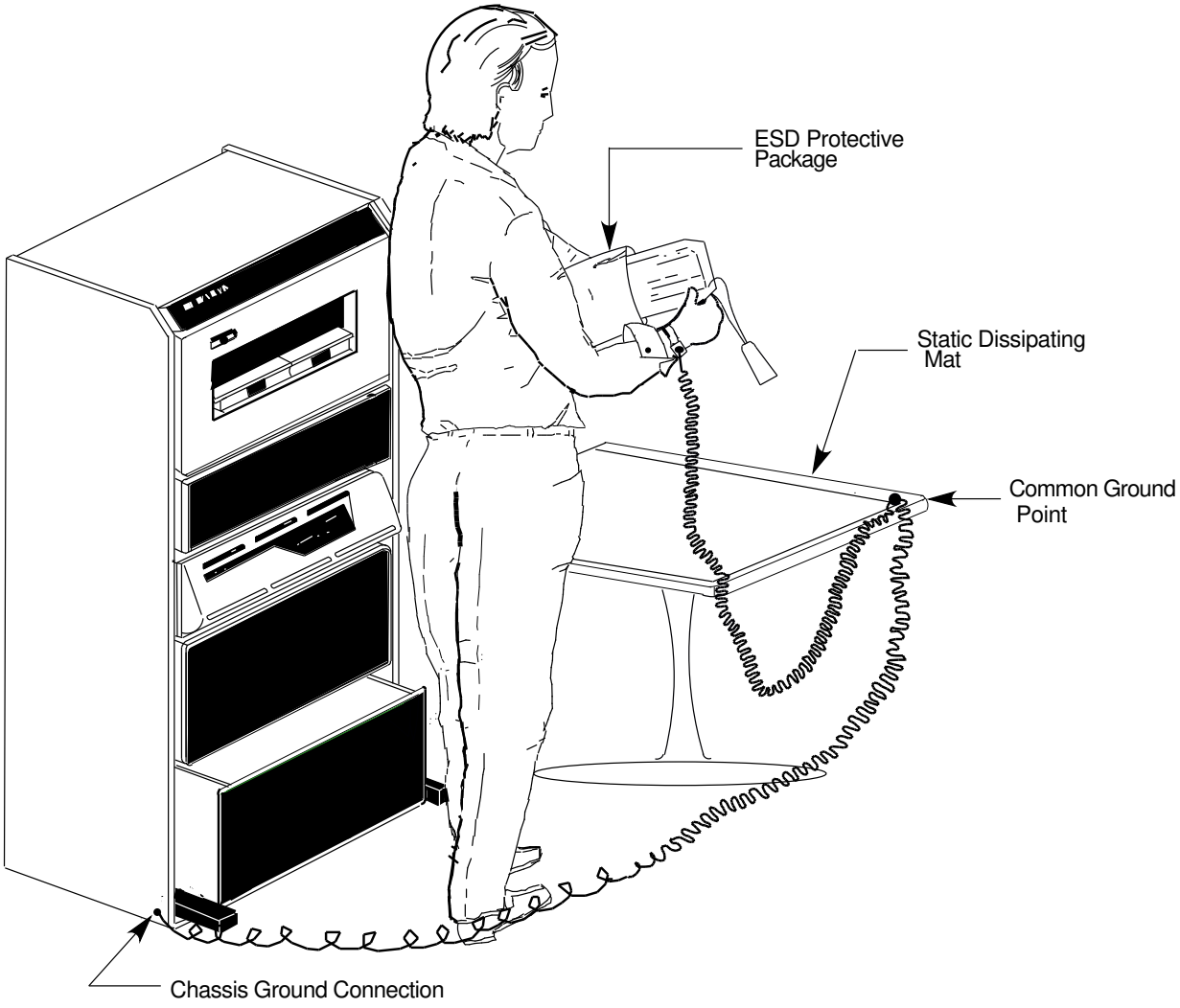
Figure 4: Typical Stand-Up Process Workstation



Rules:

1. ESD protective footware is required.
2. Wrist strap must be worn when seated.
3. ESD smock is required.
4. Remove all nonessential material.
5. Keep all sensitive material ESD protected when not being worked on.
6. Treat plastic surfaces to prevent charge generation and monitor periodically.
7. Ground all containers while transferring ESD protected contents.

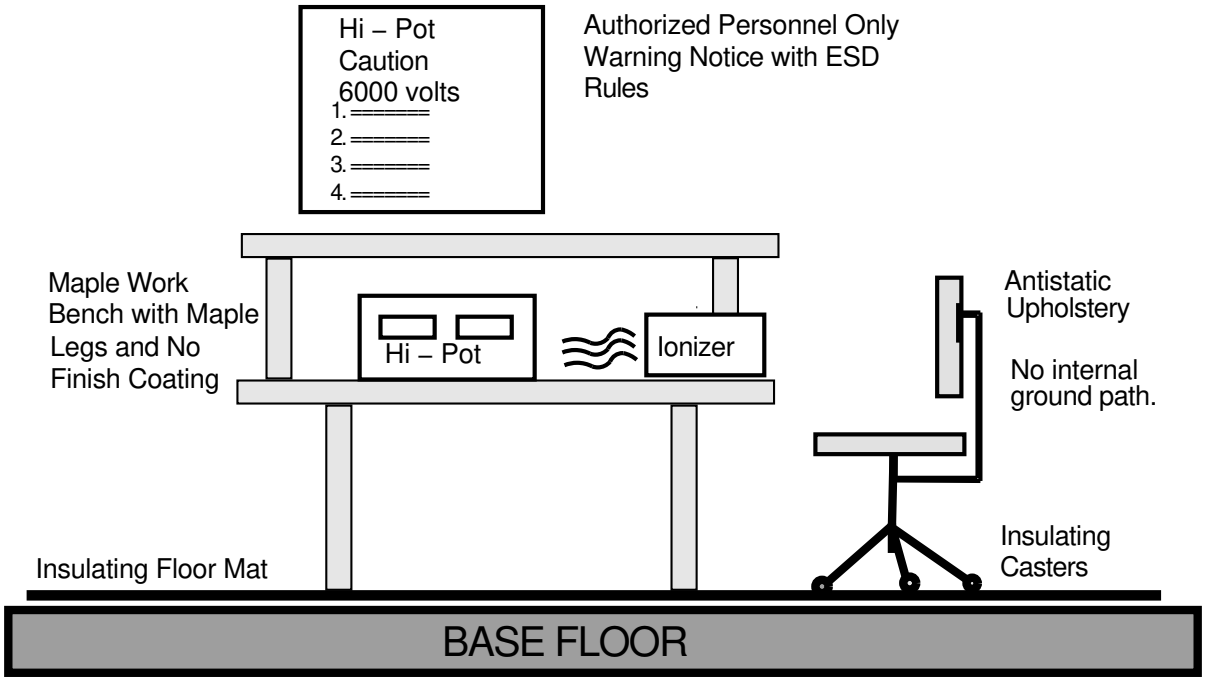
Figure 5: Typical Portable Workstation



Rules:

1. Set up ESD controls before handling components or assemblies as follows.
   - –Remove static charge generating materials from immediate area.
   - –Lay out static dissipative mat.
   - –Ground mat to equipment chassis ground.
   - –Connect wrist strap to common ground point.
2. Ground ESD protective bag/container before transferring contents in any of the following ways.
   - –Place container on mat.
   - –Hold container in hand.
   - –Attach ground cord to terminal on container.

Figure 6: Typical Hazardous Voltage Workstation

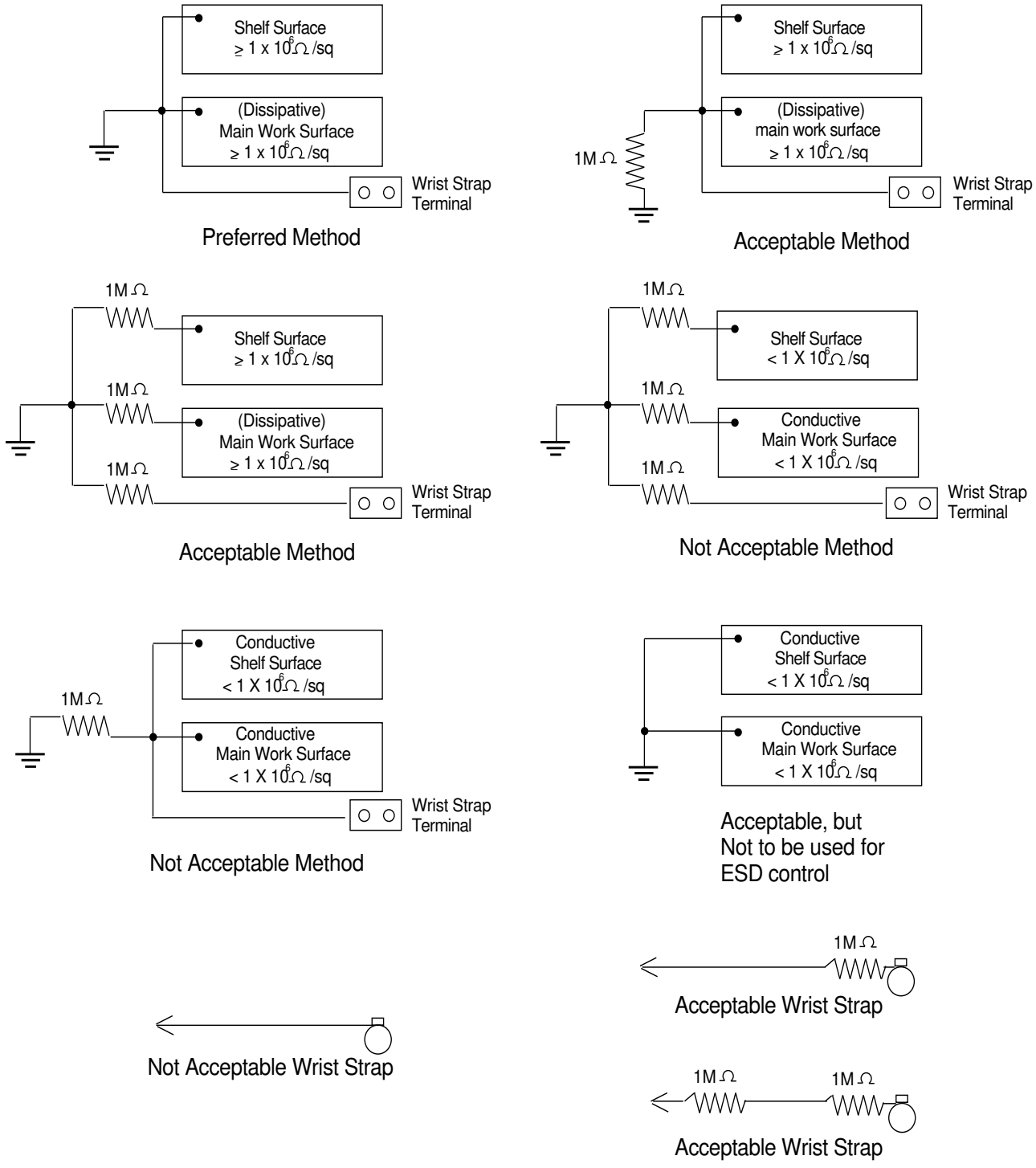


The following rules shall be applied when working in or near equipment with exposed conductors having voltages in excess of 260 volts RMS or DC (normal) and capable of producing more than 5 milliamps.

Rules:

1. ESD shoes shall be worn.
2. Shoe grounders, wrist strap, ESD smock, and jewelry shall not be worn.
3. Ionizers shall be run during operation.
4. All nonessential materials shall be removed.
5. Plastic shall be treated to prevent charge generation.
6. Floor mats shall be clearly marked "Insulating".
7. Workstations shall comply with safety procedures.

Figure 7: Typical Schematics For Workstation Work Surface and Wrist Strap Grounding



NOTE

See Section 7.1 and Section 7.2 for detailed grounding information.

4.2 HIGH VOLTAGE WORKSTATIONS

This heading applies to workstations with exposed potentials of over 260 volts dc or rms (nominal) and are capable of supporting in excess of 5 milliamps. High Potential (Hi-Pot) testing, monitor testing, power supply testing, and power control device testing are examples of high voltage workstations. Refer to Figure 6 for an example.

NOTE

Any voltage above 42.4 volts peak or 30 volts dc can be an electric shock hazard. All the workstations and procedures in the other headings of this document are designed to meet the safety requirements for exposed potentials of up to 260 volts. This section defines the requirements for personnel safety and ESD control for the workstations with a more elevated electric shock hazard of over 260 volts dc or rms (nominal). Refer to *DEC STD 119-0 Digital Product Safety - Introduction and General Requirements*, and Underwriters Laboratory 478, *Standards for EDP Equipment Product Safety*, for more information.

4.2.1 ESD Controls

ESD control is more complicated at high voltage workstations due to the need for insulating barrier materials and the requirements for personnel safety. It is possible to prevent ESD damage at these work stations by controlling electrostatic charge generation and by preventing Charged Device Model (CDM) failures through the use of highly resistive work station elements.

At high voltage workstations, extra precautions must be taken to ensure personnel safety. These precautions are defined in EL-MF277-00, *Electrical Safety Product Test Procedure*. The following ESD controls do not conflict with the safety requirements of EL-MF277-00.

1. High voltage workstations must be segregated from adjacent areas.
   - — A barrier must be placed around the perimeter of the work area that allows total visibility of the operator and the floor from all sides. (Post and chain barriers are effective.)
2. The floor must be covered with special yellow vinyl deck mat which has sufficient volume resistivity to prevent current flow in excess of 0.5 milliamps given the highest voltage available.
   - — The point to ground resistance shall be greater than 1,000 gigaohms ($1x10^{12}$ ohms). Refer to The National Fire Protection Agency NFPA99 *Standard for HealthCare Facilities* for additional information.
   - — The mat must be yellow to differentiate it from the conductive black rubber mats commonly used for ESD control.
   - — Yellow vinyl deck mat is commonly sold by material handling companies for use in wet areas in food processing and chemical industries. It is available in interlocking 12 inch squares and in rolls.
   - — Tapered nosing is available to reduce the tripping hazard at the edges.
   - — The yellow mat must extend six feet beyond the high voltage machinery on all sides.

3. An entrance barrier shall be placed on the perimeter of the yellow mat.
   - — Post CAUTION! HIGH VOLTAGE signs and AUTHORIZED ENTRY signs on all sides of the entrance barrier.
   - — It is a good practice to print the value of the highest voltage on the sign since the words "high voltage" have different meanings to people with differing backgrounds and experience.
4. All work benches at these stations shall be made of unfinished maple and shall not have exposed metal parts that could become grounded.
   - — Maple furniture will not generate or support electrostatic fields except at severely low relative humidity.
   - — Other hardwood may be substituted for maple if it has similar properties.
   - — The wood shall not have any coating applied to it such as paint, varnish, shellac, or polyurethane. A light oil rub is permissible.
5. Seating shall be non-triboelectric generating.
   - — Hardwood as described in item 4 is suitable.
   - — Antistatic or static dissipative upholstery may be used.
   - — Metal frame chairs must have large insulating pads or casters on the base that cannot puncture or get caught in the yellow deck-mat.
6. Insulating plastic sheeting, such as Lexan and Plexiglas, used as safety barriers in the test equipment shall be treated with a topical antistat at least once a week.
   - — Air ionizers shall be used to control any charge build-up on isolated conductors and on insulating materials.
   - — Ground Fault Interrupters (GFI) must be installed in the primary power circuit.
7. Wrist straps, shoe grounders, rings, watches, hanging metal jewelry or ESD smocks shall not be worn. ESD shoes are safe to wear and are recommended.
   - — Test footwear resistance before entering the workstation.
   - — Do not enter the workstation if resistance is less than one megohm.
8. Each high voltage work station must be certified by the responsible safety, electrical, and ESD engineers and by the operations manager prior to initial operation.
   - — Certification must be written and referenced to comply with the appropriate Digital standards.

5 ESD PROTECTIVE WORK AREA REQUIREMENTS

An ESD Protective Work Area shall be a bounded work space, with entrance controls. Within the boundary:

- Workstations shall be ESD protective.
- Floor, work, and storage surfaces shall dissipate electrostatic charges.
- Seats and mobile equipment shall dissipate electrostatic charges through the floor.
- Personnel shall wear ESD protective garments and footwear.
- Areas shall be free from nonessential electrostatic charge generating materials.
- Process required insulators shall be controlled by surface treatment or ionization.

Within an ESD protective Area, ESD sensitive materials are protected from ESD events, even when not enclosed in ESD protective packaging. All ESD sensitive materials must be enclosed in ESD protective packaging when brought into or taken out of the ESD Protective Area.

Packaging materials used for mechanical hardware, refuse, and other non ESD sensitive items shall not be triboelectric charge generators.

5.1 ENTRANCE CONTROL FOR ESD PROTECTIVE AREAS

Anyone entering the ESD protective area must be wearing electrostatic charge dissipating footwear or shoe grounders on both feet. Footwear must be checked for resistance at the entrance.

Footwear testers shall be available at each entrance. Footwear testers:

— Shall indicate if resistance is less than one megohm with a caution light.

— Indicate resistance is over one gigaohm with a warning light.

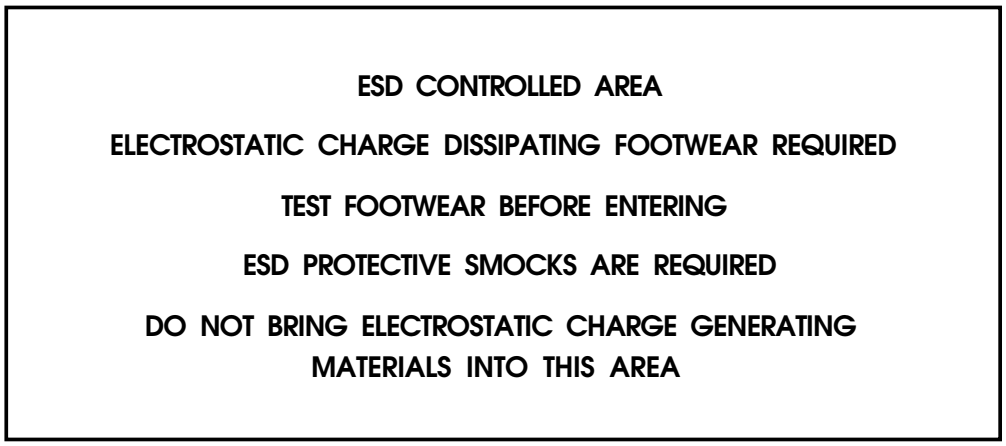
— Indicate any resistance between these extremes with a safe light. (Measurement tolerance is ±10%.)

ESD protective garments shall be worn fully closed by all people entering the protective area.

Electrostatic charge generating materials shall not be brought into the ESD protective area.

A cautionary sign shall be posted at each entrance to the ESD protective area. Refer to Figure 8.

Figure 8: Typical Entrance Sign


ESD CONTROLLED AREA
ELECTROSTATIC CHARGE DISSIPATING FOOTWEAR REQUIRED
TEST FOOTWEAR BEFORE ENTERING
ESD PROTECTIVE SMOCKS ARE REQUIRED
DO NOT BRING ELECTROSTATIC CHARGE GENERATING MATERIALS INTO THIS AREA

6 CHARGE GENERATION CONTROLS

Insulating materials used in workstation construction cannot be discharged by grounding; they must be treated with a topical antistat to prevent charge build-up. Treatment should be in accordance with manufacturer's instructions. Constant handling, cleaning, or abrading removes the coating and requires more frequent treatment. Ionization is another effective method for control of charge generation.

All static electricity generating materials shall be prohibited from ESD protective work areas. (For example, untreated plastics, styrofoams, tote boxes, tape, rubber bands, foam pads, plastic bags, plastic food containers, plant pots, trash cans, radios, ash trays, decorations, and items wrapped in cellophane.)

Triboelectric charge generating activities such as removing sweaters, collating paperwork, and brushing or cleaning charge generating material shall not be done in the ESD protected area.

Triboelectric generating tote boxes, bin boxes, and storage cabinets with untreated drawers are not allowed in ESD protected areas. Also, charge generating bags are not allowed in the area.

Non-ESD sensitive parts and hardware must be packed in antistatic bags if bags are necessary. Trash can liners used in the ESD protected area must be antistatic because of the extremely high voltage generated by common untreated bags.

6.1 HUMIDITY

Low humidity is a factor in generating high static voltages, but there is no humidity level that eliminates static electricity. Lightning storms are an example of high voltage in high humidity. Even in tropical conditions, people and objects can charge to voltage levels sufficient to damage semiconductors. ESD controls are the same for both high and low relative humidity conditions. Plant humidity control costs cannot be justified as an ESD control measure.

7 ESD GROUNDING

All grounds used for ESD control provide a path for static charges to return to the earth. The path may be through the electrical power system safety ground, the metal framework of the building, ground rods, or any verifiable connection.

- A "hard ground" is a connection to ground with very low resistance, usually 1 to 10 ohms depending on the length and gauge of the wire.
- A "soft ground" is a connection to ground with a protective current limiting resistance of at least one megohm. The resistor shall be 1/4 watt or larger, have a maximum tolerance of 10%, and be molded into a cord set or otherwise strain relieved.

ESD ground wiring should be 18 gauge or heavier for its mechanical strength. Ring lugs and threaded fasteners should be used for connections to prevent the accidental disconnects common with snaps, clips, and plugs. Wrist straps, however, are required to have a quick parting connector.

7.1 WORK SURFACE GROUNDING

The work surface shall be made of or covered with a static charge dissipating material. This surface shall be grounded to a verified earth or electrical ground. Point to ground resistance shall be equal to or greater than one megohm and less than 10 gigaohms. Refer to NFPA 99, Sec. 12-4.1.3.8. The surface resistivity shall be equal to or greater than 1×10^6 and less than 1×10^{10} ohms per square, in accordance with ASTM D 257-78 Reapproved 1983, at 100 V applied.

Dissipative work surfaces have a point to ground resistance of millions of ohms. High currents cannot flow through or across these surfaces when the supply voltage is less than 260 volts dc or rms. Adding one megohm in series has no effect on safety; it only increases the installation costs. The surface grounding connection must not be exposed.

Hard grounding of static dissipative work surfaces, greater than 1×10^6 ohms per square surface resistivity is preferred. Soft grounding is acceptable.

Conductive work surfaces can present a serious safety problem when soft grounded through a one megohm resistance. This situation occurs when a power source comes in direct contact with the work surface. The surface becomes energized to the same voltage as the power source. The one megohm resistor will neither act as a safety ground nor draw current sufficient to blow the line fuse or trip the ground fault circuit interrupter. In this situation, the entire surface can become a serious shock hazard.

Conductive work surfaces lower than 1×10^6 ohms per square are not recommended for ESD protection as they are instrumental in charged device and furniture model failures. Conductive work surfaces and bench top mats should be phased out and replaced with static dissipative materials having a surface resistivity equal to or greater than 1×10^6 ohms per square. If a conductive surface is used, it shall be hard grounded.

7.1.1 Work Surface Materials

Homogeneous volume dissipative synthetic rubber is the best choice for most applications as it is chemical, heat, and abrasion resistant. It can be permanently laminated in place when the work station is fabricated, cut to fit in the field, and applied over existing surfaces. Ground connections to this material are easily accomplished with a threaded metal fastener, washer, and ring lug terminal.

Homogeneous volume dissipative vinyl sheet and foam mat have similar ESD control properties as synthetic rubber but are not as durable.

Hard decorative laminates often allow charge retention on conductive objects placed on their surface. This is due to the laminated construction where the conductive element is buried below the surface layer. Ground connection is difficult as it must make contact with an exposed area of the conductive sublayer using special installation tools and a fastener system that includes a malleable conductive gasket or conductive epoxy.

Conductive work surfaces such as fiberglass reinforced plastic (FRP) and carbon loaded polypropylene sheet should be phased out of workstations where ESD sensitive items are handled. These surfaces are appropriate for storage and distribution areas where materials are enclosed in ESD protective containers.

NOTE

Refer to *DEC STD 067-5 Handling of Electrostatic Sensitive Devices: Materials and Equipment* for more information on work surface materials.

7.2 WRIST STRAPS

Wrist straps are the most effective method of maintaining personnel at zero static potential and are required for personnel who are seated while working on ESD sensitive product.

Wrist straps are available in several styles to suit different environments and personal comfort. In general:

— The band must be worn comfortably snug around the wrist making full skin contact.

— The wrist strap cord shall be connected to a hard ground. Connection to a soft ground is acceptable.

— Wrist strap cords must be equipped with one or two current-limiting resistors for the safety of the wearer. Resistors shall be one megohm ± 20%.

— Wrist straps with a one megohm resistor may be worn safely in areas with exposed power circuits of up to 260 volts rms or dc.

— For personnel safety, wrist straps are required to have a connection to the cuff that parts with a breakaway force of at least one pound but not more than five pounds.

— Wrist straps should not be worn when working with over 260 volts, rms, or dc of exposed power.

— Resistors used in wrist strap cords shall not change in value by more than 5%, or show any signs of physical damage when connected across 300 volts ac, and dc power sources for a period of one minute.

7.2.1 Wrist Strap Test Procedure

Wrist straps must be tested daily. Proper testing of the wrist strap must include the resistance of the cord, the limiting resistor, the snap connector, and the resistance of the interface of the band and the wrist. Proper ESD grounding requires that this resistance be at least one megohm and less than 10 megohms (± 20%).

While wearing the wrist strap, connect the loose end of the cord to the tester terminal (or ground if they are the same) and depress the test button or surface with finger or hand. If resistance is over 10 megohms, test the cord alone for continuity. If the resistance of the cord alone is approximately one megohm, check the fit of the band around the wrist and adjust it for snug fit. If the resistance is still over 10 megohms, substitute a new band. If that does not work, the problem might be dry skin. Apply some approved moisturizing lotion on the wrist and check the resistance again. (Approved moisturizing lotion does not affect solderability or contaminate gold contacts when personnel handle product.)

Constant wrist strap monitor systems are recommended for all workstations involved with high cost, state-of-the-art technology such as surface mount, Tape Automated Bonding (TAB), or complex hybrids. These high density products are difficult and expensive to repair. The total cost of the monitor can be justified by saving a single device.

7.3 FOOTWEAR

Static charge dissipating footwear is required for all personnel entering an ESD protective area. Any shoes that pass the resistance check on the footwear tester are acceptable.

1. Shoe resistance is measured while a person is wearing the shoes. Socks and hosiery do not affect resistance measurements because of their saline moisture content.
   - — Shoe resistance must be greater than one megohm and must not exceed one gigaohm.
   - — Shoe resistance shall be measured on testers made especially for that purpose.
2. In general, shoes are manufactured without concern for electrical resistance properties. ESD shoes are designed and manufactured to have a range of resistance for use in ESD protective areas.
   - — ESD shoes are available with and without steel safety toes.
   - — Shoes shall be selected from a current Recommended or Qualified Products List as shoe performance is not always consistent with advertised specifications.
   - — Refer to VTX EOS_ESD for a recommended list of shoes and grounders.

   NOTE

   Any shoe can exhibit low resistance if damp or wet. Do not work with or around exposed electric power circuits carrying over 42.4 volts peak and capable of sustaining a current of 5 mA, if shoes are damp, wet, or crusted with ice removal salt.
3. Shoe grounders are made for use on the heel or toe of ordinary shoes. They should only be used for shoes that have a resistance above one gigaohm. When needed, use on both feet.
   - — Shoe grounders must have a protective resistor between the floor contact area and the conductive ribbon.

— The resistor shall be used in shoe grounders and shall not change in value by more than 5%, or show any signs of physical damage when connected across 280 volt ac, and dc power sources for a period of one minute.

— The resistor shall not be less than one megohm +/- 20%.

4. ESD shoes are preferable to shoe grounders in almost all circumstances for the following reasons.

— Heel and toe shoe grounders only cover a small portion of the shoe bottom leaving the major portion exposed and free to tribogenerate charge.

— The voltage of a person walking while wearing shoe grounders can look like a saw tooth wave with potentially destructive high voltage spikes.

— There are several postures where the heel or toe grounders make no floor contact.

— Shoe grounders can be a tripping hazard.

— Shoe grounders have a one month life expectancy, whereas ESD shoes last about one year. A twelve month supply of shoe grounders could cost as much as four pairs of ESD shoes.

7.4 GARMENTS

ESD protective garments shall not generate more than 100 volts when rubbed. Any charge on the garment must readily drain off through the cuffs. The static voltage must decay from 1500 to 150 Volts in two seconds or less when tested in accordance with EOS/ESD Standard No. 2 drafted August 1987. Garments shall pass Hi-Pot safety tests and field attenuation tests. Refer to VTX EOS_ESD for a list of garments that pass these tests.

Garments will act as protection against ESD in the following ways. Garments:

— Perform as a Faraday Shield by containing the electric field that may exist on the untreated clothing worn by personnel.

— Shall not provide paths for harmful electric current. The resistance from hem to collar and from cuff to collar must exceed one megohm. Metal snaps may be provided for closure, cuff adjustment, and wrist strap or other ground connection. The resistance from any snap to the collar must exceed one megohm.

— Provide a continuous ground path connection to the skin of the wearer. Smocks should be ordered with elastic cuffs made from a material that has the same resistivity as the body of the garment. This is the preferred method. Snap closures are an acceptable method.

NOTE

Do not wear ESD dissipative or conductive garments when working with exposed conductors that can energize in excess of 260 Volts rms or dc nominal that are capable of sustaining more than 5 milliamps of current.

7.5 FLOOR COVERING

The floor covering shall be able to dissipate static electric charges by having an electrical resistance of less than 10 gigaohms as measured in accordance with the NFPA 99, section 12-4.1.3.8, for point to ground resistance.

Floors having a point-to-ground resistance of less than one megohm can become a hazard when personnel are working with exposed circuits of over 42.4 volts. Bare concrete, conductive floor tiles, and some ESD mats can be in this range of resistance.

NOTE

Under these circumstances, it is imperative that personnel working with exposed power circuits wear approved ESD shoes and check their resistance to ground at the start of each shift and again if shoes become wet or damp. The resistance of the shoes must be greater than one megohm. Refer to Section 7.3 for more information on footwear.

All ESD protective floor coverings must be installed and maintained according to the manufacturer's instructions. Any deviation from the manufacturer's instructions can negate the warranty and render the flooring non ESD protective. Refer to DEC STD 067-5 for a complete discussion of flooring. Refer to VTX EOS_ESD for a complete listing of floor coverings, carpets, and finishes.

7.6 SEATING

A ll seating used in ESD protective areas shall be ESD protective, as follows.

— The seating surfaces shall be non-triboelectric generating (antistatic).

— The resistance from the seat and back to the tread of the conductive casters shall be at least one megohm and must not exceed one gigaohm.

7.7 ROLLING CARTS AND EQUIPMENT

Rolling equipment used in ESD protective areas shall be grounded to the charge-dissipating floor through conductive wheels and casters. (For example: carts, hand trucks, and step ladders). All of the shelves, steps, and work surfaces shall have a conductive path to the floor through the conductive tread of the wheels. Drag chains have proven to be unreliable, especially on marbelized, conductive, vinyl composition tile floors. If the resistance measurements show the unit to be less than one gigaohm to the floor, the drag chain is acceptable.

7.7.1 Refitting Noncompliant Units

When refitting existing equipment, two conductive casters on the same side are sufficient. On wire shelf trucks, the plastic shelf connector sleeves must be replaced with metal ones on each upright over a conductive caster. Nonscratching shelf liners can be made from conductive carpeting. Liners may be fastened around the edge with tie-wraps.

8 DOCUMENTATION

Any paper, including that used in process and test documentation, can become highly charged. This depends on the fiber content, surface treatment and relative humidity. There is no way to predict the ESD hazard of paper.

The preferred method of control is to place the sheets in dissipative page protectors. An alternative is to institute controls that ensure that paper is always maintained at a distance of 12 inches from ESD sensitive components. The latter is not considered as reliable as the first and requires constant supervision.

9 POWERED HAND TOOLS

All electric power tools, including soldering and desoldering instruments, solder pots, fluxers, and cleaning equipment, shall:

— Be grounded through the electric power system's safety ground.

— Not have the capability of compromising the functional integrity of product by injecting electrical energy into the items being processed.

— Not exceed 2 millivolts rms at their tips and the resistance from tip to ground shall not exceed 2 ohms. Refer to *DOD-STD 2000-1B, Military Standard Soldering Technology* for more information.

Air and battery powered tools shall be checked by the ESD engineer for application suitability.

10 IONIZATION

Ionization is the process by which neutral atoms or molecules of air acquire a positive or negative charge. These free air ions are attracted to opposite polarity charges on surfaces where they combine and neutralize the charge. There are several types of ionizers.

1. Air ionizers:
   Air ionizers shall be used at workstations that require the use of insulators as an integral part of the process. They are also required for processes that involve air and fluid movement over the product such as hot air guns, freeze mist, particle blow-off, vacuum hold down, and vacuum cleaning. Ionization is recommended for operations where adhesive tape or labels are applied or removed from product, cleaning operations that involve brushing, and any operation that causes a 100 volt or greater field on the surface of the product.
2. Electronic air ionizers:
   Electronic air ionizers must be cleaned, inspected and balanced quarterly or more often as the manufacturer requires. Failure to do so can cause ESD damage. Maximum ionizer efficiency is maintained by frequent cleaning of the needle electrodes. Models are available with built-in brush attachments for this purpose. Units that are advertised as "self balancing" must be cleaned and checked for output and balanced quarterly.
3. Nuclear air ionizers:
   Nuclear air ionizers are safe to use but should be limited to situations that are inappropriate for electronic units, such as confined areas, wet areas or in the presence of explosive or flammable gases. Acceptable nuclear ionizers have the radio isotope

alloyed with other metals and plated onto the element. These ionizers shall be cleaned and operated in accordance with the manufacturer's instructions. The active elements are leased on a yearly basis and must be returned to the vendor for disposal or as required by contract and government regulations.

11 TEST EQUIPMENT

Test equipment shall be hard grounded to the electric power system safety ground through the ground pin of the power outlet or other connections as appropriate.

All work surfaces of console type test equipment must be charge dissipating. Insulating surfaces and conductive or bare metal surfaces must be covered with a dissipative mat or coating. This matting can be cut to fit and placed with adhesive or double sided tape. The mat must be grounded. See DEC STD 067-05.

Test fixtures shall be fabricated from ESD protective materials such as metal and dissipative or coated plastics. Do not use untreated plastics such as polycarbonate or acrylic for items like heat chambers or air baffles. Insulating plastic may be used in situations where the insulating property is process required such as high voltage barriers and to prevent inter-electrode leakage current in test heads.

12 ENVIRONMENTAL CHAMBERS

Environmental chambers should be equipped with grounded baffles to dissipate charges in circulated air. Alternately, ionized air can be used in the chamber to dissipate static charges caused by air flow.

NOTE

Caution should be used in cooling chambers with Carbon Dioxide (CO_2), since the evaporation of the CO_2 can generate high static charges.

Parts tested in temperature chambers shall be placed in ESD protective tote boxes or trays on grounded metal racks within the chamber. The thermal stability of ESD protective materials used in temperature chambers shall be suitable over the test temperature ranges.

13 AUTOMATED COMPONENT INSERTION/PLACEMENT

ESD controls for automated equipment such as component sequencing, insertion, and pick and place equipment shall comply with the general specifications of this document. Particular attention should be given to the following areas.

Charge dissipating work surfaces and floor covering must be maintained free of litter to ensure proper grounding of carts, containers, and footwear.

All equipment work surfaces must be charge dissipating. Insulating surfaces and conductive or bare metal surfaces should be covered with dissipative rubber mat. This matting can be cut to fit and put in place with adhesive or double sided tape. The mat must be soft grounded.

Triboelectric charge generating plastic windows and dividers shall be replaced with ESD protective materials as described in DEC STD 067-5. Treatment with a topical antistat is an alternate solution that requires constant monitoring and frequent retreatment.

Component tubes (such as rails, and sticks) are provided in two forms: antistatic and shielding. The transparent tubes are usually antistatic, which means they do not generate triboelectric charge or provide shielding from electrostatic fields. The black tubes, with or without a window, and metal tubes are usually conductive, shielding packages. Refer to DEC STD 067-2 for more information on packages.

ESD sensitive components in antistatic packages are not fully protected from ESD damage. Never place these packages within 12 inches of a video monitor that has a powerful electrostatic field or within 12 inches of triboelectric charge generating materials such as packaging foam. Although these foams are not allowed in the area, they are often concealed in shipping containers.

Components packed in antistatic tubes shall be stored and transported inside shielding bags or containers.

When working around automated process equipment, wrist strap ground cords may be a hazard. Proper footwear may be used for personnel grounding provided that seating is not used. Refer to Section 7 for information on footwear. If seated, a wrist strap must be worn when handling ESD sensitive product.

The automated process equipment shall be checked by the ESD engineer to ensure that the product is not exposed to electrostatic fields greater than 100 volts, triboelectric generation, or electrostatic discharge during the process.

Refer to Figure 4 for an example of a stand-up workstation.

14 ELECTRIC SHOCK SAFETY WITHIN AN ESD CONTROL PROGRAM

The risk of electric shock is likely to occur at any part if the potential between the part and the earth ground or any other accessible part, is more than 42.4 volts peak and the continuous current flows through a 1500 ohm resistor connected across the potential exceeds 5 milliamperes.

Personnel grounding for static electricity control is designed not to add any additional risk of electric shock. All personnel grounding devices and ESD control garments must have sufficient resistance to limit the flow of electric current to less than one milliamp.

For any given voltage, the intensity of an electric shock is dependent on the resistance to the flow of electric current. If the resistance limits the current to less than one milliamp, no electric shock is felt. The limit for safety is considered to be 5 milliamperes.

All personnel ESD grounding devices, such as wrist straps and heel grounders, are required to have a series resistance of at least one megohm. This may be a physical resistor or an inherent property of the material from which the device is made.

All ESD control garments are required to have a surface resistivity of at least 1×10^5 ohms per square. This translates to a resistance of around 100k ohms between points on the garment six inches apart. In Hi-Pot tests done on smocks at 280 volts dc, with five pound probes placed on the collar and hem, current flow was always less than 0.5 milliamperes.

ESD shoes are required to have a minimum resistance of one megohm and a maximum resistance of one gigaohm. This is measured with an ohm meter with a person standing in the shoes on a metal plate. The resistance reading is taken from the plate to the person's hand.

15 CLEAN ROOMS

ESD controls are more difficult to implement in clean rooms than in other areas. Processes performed in clean rooms often involve ESD sensitive materials in their most vulnerable state. These same processes often require the use of non-particulate shedding plastics for containers, trays, and "boats". This brings ESD sensitive materials into intimate contact with triboelectric charge generating plastic surfaces such as Teflon™, polyethylene, and polycarbonate. Tools, fixtures, surfaces, and garments used in clean rooms are made from nonshedding materials, films, and fabrics that can generate triboelectric charges harmful to the ESD sensitive products.

Whenever possible, ESD protective materials shall be specified as a replacement for nonprotective materials. In general, these materials should provide a controlled path to ground for accumulated charge.

It is not always possible to find an ESD protective substitute for all of the charge generating materials used in a clean room. In these cases, charge generation is controlled by sophisticated room and hood ionization systems. There are several types of ionization systems available and each has its advantages and disadvantages. Some systems do not perform as well as others. It is necessary to obtain expert guidance in making a selection. For a complete discussion of room ionization systems, refer to DEC STD 067-5.

Desiccator cabinets and product storage equipment shall be fabricated from ESD protective materials. Refer to DEC STD 067-05.

Static charges can cause a variety of problems that affect quality and reduce yields. A sensitive static field meter with 10 volt resolution shall be used to detect charges on product and nearby objects and surfaces. When static fields are found, the responsible ESD engineer shall evaluate the situation and implement necessary controls.

In general, all of the requirements of this standard shall be applied to the workstations, equipment, and personnel operating in a clean room to an extent consistent with clean room standards. Whenever electrostatic charges are found to have a negative effect on product quality, action must be taken to remedy the problem.

16 MASS SOLDERING

ESD controls for soldering and cleaning printed circuit modules shall comply with the general specifications of this document. Particular attention should be given to the areas mentioned below.

Charge dissipating work surfaces and floor covering must be cleaned and maintained in good condition. Accumulation of process materials or chemicals can reduce or destroy the ESD protective properties of the surface.

When working around automated process equipment, wrist strap ground cords may be a hazard. Proper footwear may be used for personnel grounding provided that seating is not used. If seated, a wrist strap must be worn when handling ESD sensitive product.

Heat and chemical resistant gloves and garments worn while handling product shall be ESD protective.

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The automated process equipment shall be checked by the ESD engineer to ensure that the product is not exposed to electrostatic fields greater than 100 volts, triboelectric generation, or electrostatic discharge during the process.

The equipment shall not be capable of injecting electrical energy into the product. The resistance between ground and the parts of the machine that touches the product shall be no greater than 2 ohms. The voltage difference between ground and product being soldered or cleaned shall be no greater than 2 millivolts.

16.1 STORAGE AND DISTRIBUTION

Storage and distribution include the following operations: receiving, incoming inspection, stocking, kitting, boxing, and transport. The following are requirements for ESD control in these operations.

— Grounded work surfaces and the floor shall be maintained clear of packaging materials such as cushioning material, void fillers, tape, stickers, document pouches, plastic wrap, fiber board, and paper. These materials can prevent proper grounding to the surface.

— All ESD sensitive product shall be stored and transported inside ESD protective containers or packaged per DEC STD 067-2.

— ESD sensitive product packaged in sealed ESD protective containers may be handled by untrained personnel and may be stored and transported in uncontrolled environments.

— Deboxing shall be performed in an ESD controlled area by properly grounded personnel.

— ESD protective packaging shall not be opened except at an ESD controlled work station by trained and certified personnel who are properly grounded.

— Unprotected ESD sensitive product shall not be handled except at an ESD controlled work station by trained and certified personnel who are properly grounded.

17 TRAINING

ESD awareness and control procedures shall be provided to all personnel who specify, procure, design, or handle ESD sensitive items as well as the responsible management. The most extensive ESD protective handling procedures and controlled environments will not provide the protection needed if people are not properly trained. ESD training programs shall be oriented to the facility and the types of ESD protective materials and equipment that have been found to be effective for the particular application.

Personnel shall be trained to effectively employ the ESD protective materials and equipment provided, and to understand the theory behind many of the ESD precautions included in the ESD handling procedures and in grounding safety precautions. ESD awareness shall also be a part of equipment training courses.

The skill level of the trainees also has a bearing on the ESD training provided. The depth of theory on static electricity should depend upon the trainee's needs, and be directly related to the job function. Certification of satisfactory completion of the training course shall be documented for people who have attended and demonstrated a comprehension of the elements of the training course through written examination. Personnel shall be recertified annually.

Table 1: Training Program for ESD Control Module Matrix

	AUDIENCE		
MODULES	OPERATORS	ENG/TECH	MANAGEMENT
Awareness	Nontechnical	Technical	Financial and R.O.I.
Physics	Nontechnical	Technical	Technical as applicable
Control Principles	Simple	Detailed	Detailed
Operational Procedures	Basic	Basic	Basic
Workstations	Use	Design and Set-up	Description and Cost
Grounding	Safety	Safety Parameters, Design	Safety
Apparel	Use and Care	Use, Care and Testing	Use, Maint. and Cost
Monitors and Checkers	Use	Use/Selection	Use/Justification
Ionization	Use	Use and Maint.	Use and Cost
Storage and Distribution	Handling	Handling	Process Control

17.1 SUPPLEMENTAL TECHNICAL MODULES

Additional information is available in the following supplemental modules.

— ESD Controls for Component Insertion Areas

— ESD Controls for Mass Soldering Stations

— ESD Controls for High Voltage Hazard Workstations

— ESD Controls for Semiconductor Manufacturing

— ESD Controls for Clean Rooms

18 AUDIT PROCEDURES

ESD controlled areas shall be audited for compliance to the requirements of this standard on a periodic basis. The results of the audit shall be compiled and maintained for comparison with previous and subsequent audits. It is helpful to plot a pareto chart of these results for each area or cost center. This way trends can be spotted and problems can be addressed.

The results of the audit should be discussed at a subsequent operation's staff meeting following the audit. Remedial action plans should be approved at the meeting.

Refer to Appendix B for an example of a Sample Audit Checklist.

APPENDIX A REFERENCE DOCUMENTS

A.1 EL-Class Digital Documents

EL-Class Number	Document Title
EL-00067-00	*DEC STD 067-0 Electrostatic Discharge - Sensitive Devices*
EL-00067-01	*DEC STD 067-1 Electrostatic Discharge-Sensitive Devices: In Engineering Facilities*
EL-00067-02	*DEC STD 067-2 Packaging of Electrostatic Discharge-Sensitive Devices: Procedures and Protective Packaging Materials*
EL-00067-04	*DEC STD 067-4 Handling of Electrostatic Discharge Sensitive Material (ESD) in all Field Service Operations and Logistics Areas*
EL-00067-05	*DEC STD 067-5 Electrostatic - Sensitive Devices: Related Materials and Products*
EL-00119-00	*DEC STD 119-0 Digital Product Safety - Introduction and General Requirements*
EL-MF277-00	*Electrical Safety Product Test Procedure*

Use VTX SMC to order copies of EL-class documents from Standards and Methods Control. Send distribution questions to JOKUR::SMC or call DTN: 234-4423.

A.2 Ordering Information

Following are the sources for documents not available from Standards and Methods Control.

- ANSI, IEC, and ISO Documents
  American National Standards Institute (ANSI),
  1430 Broadway, New York, NY 10018,
  Telephone (212) 354-3300 x479
- American Society for Testing and Materials (ASTM),
  1916 Race Street,
  Philadelphia, PA 19103
- Underwriters Laboratories (UL), Publications Stock,
  33 Pfingsten Road, Northbrook, IL 60062,
  Telephone (312) 272-8800, x2612 or x2622

APPENDIX B SAMPLE ESD CONTROL AUDIT CHECKLIST

This is a sample audit checklist that can be used as a guide for writing a site specific checklist. The structure is a brief list of the site ESD rules. As the auditor reviews an area, the the number of items in compliance and the number of violations found are logged in the appropriate column and row with hash marks. These can be subtotaled for each block at the end of the audit. Column totals may be used as an index of compliance that can be compared with previous and subsequent audits. If comments or further descriptions are required, they should be written on a separate sheet and given an index number to be placed in the last column. For simplicity, all ESD sensitive components, assemblies, and modules will be referred to as product.

Figure 9: Sample Audit Checklist

PROGRAM REQUIREMENTS	QUANTITY THAT COMPLY	NUMBER OF VIOLATIONS	COMMENT NUMBER
ESD protective work stations shall be clearly posted.			
ESD protective areas shall be defined by walls, partitions, floor markings, or other suitable means.			
Entrances to an ESD Protective Area shall be restricted to authorized personnel. Visitors shall be guided.			
Personnel in an ESD Protective Area shall wear an ESD controlled smock, fully closed.			
Personnel in an ESD Protective Area shall wear ESD dissipative shoes or two shoe grounders.			
Personnel in an ESD Protective Area shall test footwear when entering an ESD area.			
All seated personnel shall wear a properly fitting wriststrap connected and grounded.			
All wrist straps shall be checked daily.			
Wrist strap checkers shall be accessible to all personnel.			
All work and shelf surfaces of an ESD protective workstation shall be static dissipative and connected to ground.			
Point-to-ground resistance of a work surface (at center) shall be greater than 1 megohm and less than 10 gigaohms.			
ESD protective workstations shall be equipped with at least one wrist strap ground terminal wired to earth ground.			
ESD protective flooring shall have a point-to-ground resistance less than 10 giggaohms.			
ESD protective flooring shall be maintained with materials that do not degrade the ESD protection.			
Seating in an ESD Protective Area shall be static dissipating and grounded to the ESD protective floor through conductive casters.			

Sample Audit Checklist, continued

PROGRAM REQUIREMENTS	QUANTITY THAT COMPLY	NUMBER OF VIOLATIONS	COMMENT NUMBER
Carts and mobile equipment shall be grounded to the ESD floor through conductive casters.			
Documentation shall be in static dissipative page protectors or maintained more than 12 inches from product.			
Personnel shall have received ESD control training within 12 months.			
Product shall be handled by grounded personnel.			
Product shall be handled at ESD protective work station or within an ESD protective area.			
ESD protective transport shall be required for all products entering or leaving an ESD protective area.			
ESD protective transport shall be required for all products entering or leaving an ESD protective workstation that is not inside an ESD protective package.			
Product shall not be placed on an insulating surface unless enclosed in ESD protective packaging.			
Static generating items shall not be allowed in ESD protective areas and workstation areas unless they are required for process.			
Static generating items shall be controlled by surface treatment or ionization.			
All electronic ionizers shall have an inspection sticker showing calibration within the last three months.			
Nuclear ionizer elements shall not be out of date. (Mfg. label)			

GLOSSARY

antistat: Chemical compound which when impregnated in or topically applied to a primary material or substrate renders the primary material antistatic.

antistatic: A property of materials that resists triboelectric charging when separated from themselves or other materials.

conductive: A property of materials which are either metal or impregnated with metal, carbon particles or other conductive materials, or whose surface has been treated with such materials. A conductive material for static control purposes shall have a surface resistivity less than $1x10^5$ ohms/square or $1x10^3$ ohm-cm if volume conductive.

electrostatic charge: An electrical charge at rest. (Refer to static electricity.)

electrostatic discharge (ESD): The transfer of electrostatic charge between bodies at different electrostatic potentials.

electrostatic field: The region surrounding an electrically charged object.

electrostatic potential: The potential difference between a point and an agreed-upon reference.

electrostatic shield: A barrier or enclosure that prevents the penetration of an electrostatic field.

ESD: Refer to electrostatic discharge.

ESD garment: Clothing manufactured from fabrics specially designed or treated to inhibit the buildup of electrostatic charge, and to shield the static electric field on an individual's clothing.

ESD protective: A property of materials capable of one or more of the following: preventing the generation of static electricity, safely dissipating electrostatic charges over its surface or volume, or providing shielding from electrostatic fields or ESD.

ESD protected work station/area: A workstation or an area which is constructed and equipped with the necessary ESD protective materials and equipment to limit ESD voltage below the sensitivity level of ESD sensitive items handled therein.

ESD protective work surface: Any work surface designed to minimize static charges, by connecting them to the ground and preventing triboelectric generation.

Faraday Shield/Cage: A network of parallel wires connected to a common conductor at one end to provide electrostatic shielding without affecting electromagnetic waves. The common conductor is usually grounded.

ground: A metallic connection with earth to establish zero potential or voltage with respect to ground or earth. A "hard ground" has the same definition. A "soft ground" has a current limiting series resistance, usually one megohm, for personnel safety.

insulative material: A material having a surface resistivity of at least $1x10^{12}$ ohms/square, or $1x10^{10}$ ohm-cm volume resistivity.

ionization: The process by which a neutral atom or molecule, such as air, acquires a positive or negative charge.

static dissipative: A property of material having a surface resistivity of at least $1x10^{5}$ ohms/square or $1x10^{3}$ ohm-cm volume resistivity, but less than $1x10^{12}$ ohm/square surface resistivity or $1x10^{10}$ ohm-cm volume resistivity.

static electricity: An electrical charge at rest. The electrical charge is due to the transfer of electrons within a body (polarization) or from one body to another.

surface resistivity: The ratio of dc voltage to the current that passes across the surface of a system. In this case, the surface consists of a square unit of area. In effect, the surface resistivity is the resistance between two opposite sides of a square and is independent of the size of the square or its dimensional units. Surface resistivity is expressed in ohms per square.

topical antistats: Those chemical agents which when applied to surfaces of insulative materials will reduce their ability to generate electrostatic charge.

triboelectric charging: The generation of electrostatic charges when two pieces of material in intimate contact are separated. Usually one or both is an insulator. Rubbing surfaces together increases the amount of charge generated.

voltage suppression: A phenomenon where the voltage from a charged object is reduced by increasing the capacitance of the object rather than decreasing the charge on the object. Governed by the relation Q = CV.

volume resistivity: The ratio of the dc voltage per unit thickness applied across two electrodes in contact with a specimen to the amount of current per unit area passing through the system. Volume resistivity is generally specified in ohm-centimeters.

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